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Assessment of physical and energetic characteristics of pellets produced from *Elaeis guineensis* shells, *Cocos nucifera* fibers and *Distemonanthus benthamianus* sawdust

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Abstract

This study seeks to examine the sustainable energy valorisation of three Cameroonian biomass residues—palm nut (*Elaeis guineensis)* shells, coconut (*Cocos nucifera)* fibres, and movingui (*Distemonanthus benthamianus)* sawdust—via pelletisation. The raw materials were first dried, milled, and sieved, then formulated into pellets without any binders. Key physical and thermal characteristics, including moisture content, higher calorific value (HCV), volatile matter, ash content, and fixed carbon, were evaluated. Thermogravimetric analysis (TGA), coupled with differential scanning calorimetry (DSC), was applied to assess thermal behaviour. The principal results indicate that palm nut shells showed the highest calorific value (18.89 MJ/kg), whereas coconut fibres presented the lowest (16.43 MJ/kg). Among the mixtures, pellets containing 10% fibres, 30% movingui sawdust, and 60% palm nut shells (10F30M60C) displayed the greatest energy potential, with an HCV of 25.07 MJ/kg and a fixed carbon content of 24.94%. TGA profiles indicated that blended pellets decomposed over a broader temperature interval (200°C–565°C), reflecting enhanced thermal stability relative to unblended residues. The findings indicate that these biomass combinations may represent viable alternatives to firewood and fossil fuels for domestic heating, as their characteristics closely align with international references. This study contributes to sustainable biomass utilisation strategies and reinforces energy diversification efforts in sub-Saharan Africa.
Keywords: **Agroforestry residues, Biomass pellets, calorific value, thermogravimetric analysis**

1 Introduction

The worldwide demand for energy has experienced a remarkable increase over the last five decades, largely driven by rapid industrialisation, technological progress, and accelerated population growth (Bot et al., 2023; Sakellariou et al., 2022). This growing demand has been mainly met through fossil energy sources—coal, oil, and natural gas—which currently represent nearly 80% of global primary energy consumption

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(Kidmo et al., 2021). Although these resources have underpinned economic development, they have simultaneously caused serious environmental consequences, notably greenhouse gas emissions, atmospheric pollution, and climate change (Sthel et al., 2025). In addition, geopolitical instability affecting fossil fuel markets has heightened concerns related to energy security and cost, particularly within low- and middle-income countries. Sub-Saharan Africa remains among the regions most severely impacted by energy poverty, with more than 600 million people lacking access to reliable electricity and over 80% depending on traditional biomass—mainly firewood and charcoal—for cooking and heating purposes (Sthel et al., 2025). In countries such as Cameroon, this reliance has resulted in extensive deforestation, ecosystem degradation, and respiratory illnesses linked to indoor air pollution. Consequently, there is a pressing need to identify alternative, decentralised, and clean energy solutions that are locally available, sustainable, and suitable for rural and peri-urban settings (Andigema et al., 2024).

Among renewable energy options, biomass presents considerable potential, particularly in regions rich in agricultural and forest resources (Bot et al., 2022). Biomass refers to organic matter originating from living or recently living organisms, including wood, agricultural residues, animal waste, and industrial by-products (Nisha et al., 2024). In Cameroon, a wide range of biomass residues is produced through agro-industrial and forestry activities (Bot et al., 2022; Estella et al., 2016). These residues include palm nut shells from palm oil processing, coconut husks from fruit industries, and sawdust from both primary and secondary timber processing. However, such materials are frequently discarded, left to decompose, or openly burned, leading to environmental pollution and a loss of potential energy resources. Converting these residues into usable energy carriers offers a dual benefit: reducing the environmental impacts of agricultural and forestry practices while contributing to national and regional energy supply. Nonetheless, untreated biomass faces major limitations, including high moisture levels, low energy density, poor combustion performance, and material heterogeneity, which restrict its direct utilisation as fuel.

To overcome the constraints associated with raw biomass and promote its use as a modern energy source, pelletisation has emerged as a widely implemented technological solution (He et al., 2024). Pelletisation is a mechanical densification technique that converts loose biomass into compact, cylindrical, high-energy pellets (Yilmaz et al., 2025). This process enhances the physical, thermal, and handling characteristics of biomass, such as increased calorific value, lower moisture content, uniform geometry, and improved combustion efficiency (Asif et al., 2025). Moreover, biomass pellets represent a cleaner alternative to firewood and charcoal, with reduced pollutant emissions. Pelletisation also allows for the combination of different residues, which may generate synergistic effects and lead to improved pellet quality (Pierre et al., 2021). Blending woody and fibrous materials—such as sawdust and coconut husks—can enhance mechanical strength and combustion behaviour without requiring chemical binders (García et al., 2019). In addition, lignin present in woody biomass acts as a natural binding agent during pellet formation at elevated temperatures, minimising the need for additives (Park et al., 2020). Despite these benefits, pellet technology adoption in sub-Saharan Africa remains limited due to

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technical, economic, and institutional challenges. Nevertheless, it constitutes a promising pathway for sustainable bioenergy development within the region.

Numerous studies have focused on characterising the fuel properties of individual biomass residues considered in this research and assessing their suitability for pellet production. Palm nut (*Elaeis guineensis*) shells, for example, are recognised for their high fixed carbon content and elevated calorific value, making them appropriate for thermal energy applications (Duku et al., 2011; J.K. Odusote, 2017; Vitoussia et al., 2021; Yahayu et al., 2018). Coconut (*Cocos nucifera)* fibres, although more fibrous and associated with higher ash content, contribute to pellet binding and enhance mechanical durability (Liu et al., 1494; Stelte et al., 2019). Movingui (*Distemonanthus benthamianus)* sawdust, derived from a native West African hardwood species, has been identified as having a favourable lignocellulosic structure and moderate energy potential (Mfomo et al., 2020; Misse et al., 2018; Muhammed Raji et al., 2025). However, each material presents limitations when used individually: palm nut shells are difficult to densify, coconut fibres tend to generate higher ash levels, and sawdust-based pellets may exhibit reduced mechanical durability. While previous research has documented the properties of pellets produced from these materials separately, limited attention has been given to their synergistic blending to optimise both physical and thermal characteristics. Existing studies often lack a comprehensive evaluation of moisture content, bulk density, ash behaviour, fixed carbon, and thermal degradation profiles of blended pellets. Consequently, further applied research is required to integrate detailed experimental characterisation with practical guidance for local and regional energy planning.

Considering the gaps identified above, this study seeks to answer the following question: *How can agro-industrial and forestry residues such as palm nut shells, coconut fibres, and movingui sawdust be effectively blended and densified into solid biofuels exhibiting enhanced energy performance?* This research adopts an experimental approach focused on mixing locally available biomass residues in defined proportions, without the use of chemical binders, in order to produce high-performance fuel pellets suited to domestic thermal applications. In contrast to earlier studies, this work integrates detailed physico-chemical characterisation with advanced thermal techniques—specifically thermogravimetric analysis (TGA), derivative thermogravimetry (DTG), and differential scanning calorimetry (DSC)—to evaluate the behaviour of the resulting pellets under realistic combustion conditions. The main objective of this study is to assess physical and energetic characteristics of pellets produced from agricultural and forestry biomass.

2 Materials and Methods

2.1 Collection of Raw Materials

Three biomass residues that are widely available in Cameroon were selected for this investigation: palm nut shells, coconut fibres, and movingui sawdust. Palm nut shells were collected from a palm oil processing unit in Song-Mayo, Pouma District (Littoral Region). Coconut fibres were sourced from traders operating at the Edéa municipal market. Movingui sawdust was obtained from a sawmill situated in Ndogbong, Douala. Fresh raw biomass materials are illustrated in Figure 1. The overall

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methodological framework adopted in this study was developed by (Bot, Sosso, et al., 2022; Vitoussia et al., 2021). After collection, the residues were sun-dried for a period of two weeks under ambient conditions (25–32 °C) in order to reduce their moisture content prior to further treatment. The dried materials (shown in Figure 2) were subsequently visually examined and manually cleaned to eliminate impurities. Representative samples of each residue were then placed in sealed containers to prevent moisture uptake before laboratory analyses.

Figure 1: (A) Palm nut tres **(B)** Coconut tree **(C)** Movingui tree

a) **b)** **c)**

Figure 2: (a) Palm nut shells (**b)** Coconut fibers **(c)** Movingui sawdust

2.2 Sample Preparation and Pellet Formation

All raw materials were initially milled using a hammer mill equipped with a sieve to ensure uniform particle size, with particle diameters ranging between 0.5 and 1.5 mm. The resulting powders were then blended according to specific mass-based ratios to obtain three composite formulations, as presented in Table 1.

Table 1: Proportions of raw materials

Sample	Proportions
10F30M60C	10% coconut fibres, 30% movingui sawdust, 60% palm nut shells
10F60M30C	10% coconut fibres, 60% movingui sawdust, 30% palm nut shells
33F33M33C	33% coconut fibres, 33% movingui sawdust, 33% palm nut shells

The blending proportions were determined based on preliminary calorific value measurements and existing literature on selected pellet formulations (Kamga et al., 2024; Vitoussia et al., 2021). No chemical binder was added; instead, cohesion during densification was ensured by the natural lignin present in the biomass residues. Under the combined effect of heat and pressure, lignin softens and migrates toward the particle surfaces, acting as a binding agent upon cooling. Pelletisation was performed using a flat die pelletiser of model CAZL200C (series no. 201406058), fitted with a 3 kW motor and operating at a frequency of 50 Hz. Pellet production was conducted at an average die temperature ranging from 90 to 100 °C, and the pellets were cut into cylindrical lengths of approximately 10–13 mm.

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2.3 Physical Characteristics

To determine the mean length and diameter of the produced pellets, a set of 50 pellets per formulation was measured using a digital vernier calliper with a precision of 0.01 mm. The cross-sectional area was calculated based on the geometry of the pellet die.
The bulk density of the pellets was determined as the mass-to-volume ratio, in accordance with the procedure reported by Liu et al. (2013). The volume (V) of individual pellets was calculated as:

$$V = \pi \times \left(\frac{d}{2}\right)^2 \times h \quad (1)$$

where d is the pellet diameter and h is its height.
The mass (m) was measured using a high-precision digital analytical balance (EK5150, maximum capacity 250 g). The density was subsequently calculated using:

$$\rho = \frac{m}{V} \quad (2)$$

2.4 Proximal characteristics

2.4.1 Moisture Content

The moisture content was evaluated in accordance to CEN/TS 14774-2005 standard The pellets were initially weighed and noted M_b, then the briquettes were dried in a dryer model 101-1AS for 24 h at 105 °C and weighed afterwards and noted M_c. The difference in mass of the samples before and after drying was determined to evaluate the moisture content according to the formula presented in the following equation:

$$MC = \frac{M_b - M_s}{M_b} \times 100 \quad (3)$$

2.4.2 Ash content

The ash content (AC) was determined in accordance with ISO 18122:2015, which involves incinerating the samples in a muffle furnace at 550 °C until complete removal of organic matter is achieved. The resulting ash mass was subsequently expressed as a percentage of the original sample mass (ISO 18122:2022, 2022).

2.4.3 Volatile Matter

The volatile matter (VM) content was evaluated in accordance with the EN ISO 18123:2015 standard. The samples were heated at 900 °C for 7 minutes in a sealed crucible, and the VM (%) was determined from the mass loss after subtracting the moisture content (ISO 18123, 2023).

2.4.4 Fixed Carbon

The fixed carbon (FC) content was indirectly calculated from the proximate analysis

$$FC = 100 - (MC + VM + AC) \quad (4)$$

following the approach reported by Bot et al. (2022):

2.5 Higher Calorific Value (HCV) Measurement

The Higher Calorific Value (HCV) of each sample was determined using a bomb calorimeter (XRY-1A) in accordance with the EN 14918 standard (EN 14918, 2009). Approximately 1 g of oven-dried sample was combusted within a sealed vessel

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pressurised with 25 bar of pure oxygen, and the resulting temperature rise of the surrounding water bath was recorded with a precision of 0.001 °C. Calibration of the calorimeter was performed using benzoic acid as the reference substance.

2.6 Thermogravimetric and Thermal Behaviour Analysis

To assess thermal stability and decomposition behaviour, Thermogravimetric Analysis (TGA) was conducted using a LINSEIS STA PT-1000 apparatus. The system is equipped with a high-precision microbalance, a programmable heating furnace capable of reaching temperatures up to 1600 °C, and a thermocouple-regulated atmosphere. For each test, approximately 10 mg of sample was heated from ambient temperature to 600 °C at a constant heating rate of 10 °C/min under air atmosphere.

2.7 Statistical analysis

Three replicates were carried out for each experimental parameter, and the corresponding mean values and associated errors were calculated. Following the methodology adopted by Carroll and Finnan (2012) (Carroll & Finnan, 2012), the collected data were entered into an Excel worksheet and subsequently analysed using SPSS (Statistical Package of Social Science) software, version 22.0. Statistical comparisons among the evaluated parameters were performed using analysis of variance combined with Duncan post hoc tests, with statistical significance defined at $p < 0.05$.

3 Results and discussion

3.1 Physical properties of the pellets

Physical properties of the manufactured pellets, including mean length, mass, volume, and bulk density, are presented in Table 2 below. These parameters strongly affect the mechanical durability, energy density, and handling behaviour of the fuel pellets during use.

Regarding pellet length and shape compliance, all samples met the EN+ standard requirements, which specify acceptable pellet lengths ranging from 3.15 to 40 mm. Pellets produced from movingui sawdust exhibited the greatest average length (12.73 mm), whereas the 10F30M60C formulation yielded the most compact pellets (9.65 mm), most likely due to the higher lignin contribution from palm nut shells promoting shrinkage during the cooling stage. Concerning mass and volume, it was observed that pellets derived from coconut fibres were the heaviest (0.51 g), reflecting their fibrous and relatively dense structure. Nevertheless, this higher mass did not result in superior energy density because of the lower calorific value and elevated ash content. In contrast, the 10F30M60C and 10F60M30C blends exhibited a more balanced mass-to-volume ratio, which favoured improved stability of energy density.

Pellets	Average length (mm)	Average mass (g)	Volume (cm^3)	Bulk density (g/cm^3)
Coconut fibers	10.65± 2.10	0.51± 0.07	0.76±0.13	0.67±0.20

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Movingui	12.73 ± 2.83	0.30±0.08	0.64±0.16	0.45±0.23
33F33M33C	10.55± 1.10	0.34± 0,07	0.54±0.02	0.57± 0.14
10F30M60C	9.65± 1.10	0.40± 0.04	0.55±0.09	0.72± 0.14
10F60M30C	11.49± 1.65	035± 0.06	0.54±0.11	0.59± 0.21
Pellets EN+ standard	3,15 ≤ L≤ 40			≥ 0.6

Table 2: The produced pellets' average length, bulk density, and EN+

With regard to bulk density, the 10F30M60C pellets recorded the highest value (0.72 g/cm³), clearly exceeding the EN+ requirement (≥0.60 g/cm³). This outcome indicates a high level of compaction, strong inter-particle cohesion, and enhanced energy storage per unit volume. Pellets produced from coconut fibres also met the EN+ density criterion (0.67 g/cm³); however, their comparatively low HHV and mechanical irregularities restrict their practical applicability. In contrast, pellets composed solely of movingui sawdust showed the lowest bulk density (0.45 g/cm³), which can be attributed to weaker compaction and reduced natural binding capacity. Densification generally leads to pellets characterised by elevated density and calorific value (Piednoir Brice, 2017). Moreover, according to Obernberger Ingwald and Thek Gerold (2010), pellets with higher density exhibit longer combustion durations, suggesting that 10F30M60C pellets would present the longest burning time, followed by 10F60M30C and 33F33M33C pellets.

3.2 Proximal characteristics of pellets

Proximate analysis—comprising moisture content (MC), volatile matter (VM), ash content, and fixed carbon (FC)—plays a key role in assessing combustion behaviour, thermal efficiency, and the environmental performance of biomass-based fuels. Table 3 below reports the experimental values obtained for each pellet formulation alongside the corresponding benchmark limits specified by the EN+ standards.

Table 3: Proximal analysis of processed pellets and EN+

Samples	MC (%)	VM (%)	Ash (%)	FC (%)
Coconut fibers	7,66±0,90	68,7±4,65	5,14±0,65	18,50±1,2
Movingui	6,13±0,65	69,94±5,1	5,22±0,56	18,71±1,1
33F33M33C	4,36±0,87	68,53±5,8	6,52±0,92	20,59±1,6
10F30M60C	4,30±0,43	64,72±4,9	6,04±0,55	24,94±1,2
10F60M30C	4,15±0,36	69,61±5,54	5,77±0,85	20,47±1,3
EN + standard (Vitoussia et al., 2020)	<8	12,7	0,3	79,3

3.2.1 Moisture content

All samples displayed low moisture contents (≤ 7.7%), remaining well below the EN+ upper limit of 8%. This condition promotes improved combustion efficiency and better storage stability. The blended pellets, particularly 10F30M60C and 10F60M30C, exhibited the lowest MC values (~4.2–4.3%), thereby enhancing net calorific value and

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minimising ignition delay. This behaviour indicates effective drying and a synergistic moisture-reducing influence of palm nut shells. In comparison with EN+ reference pellets, the produced pellets showed lower moisture contents. These findings are consistent with those reported by Kamga et al. (2024), where pellet moisture levels were similarly lower than EN+ specifications. Pellets are considered highly energy-efficient fuels due to their reduced moisture content, as up to 90% of the material contributes directly to useful heat generation (Piednoir Brice, 2017). Since part of the combustion heat is consumed in vaporising inherent water, moisture content directly affects ignition behaviour, making it a critical factor during pellet production, storage, and transportation (Carroll & Finnan, 2012).These findings corroborate with those of (Vitoussia et al., 2020), where the resulting pellets had lower moisture content(4.25-5.89 %) than EN+ pellets.

3.2.2 Volatile matter content

The results indicate that the highest volatile matter content (69.94%) was recorded for movingui sawdust, followed by pellets formulated with the 10F60M30C blend (69.61%) and coconut fibre pellets (68.7%). In contrast, the lowest volatile matter content was observed for the 10F30M60C pellets (64.72%). This trend can be explained by the requirement of approximately 40% volatile matter to avoid fuel ignition accompanied by excessive smoke formation (Vitoussia et al., 2020). The volatile matter contents of all pellets produced in this study are significantly higher than the recommended threshold and exceed those reported for EN+ certified pellets. Consequently, these pellets are expected to ignite easily within the observed volatile matter range and may generate a certain amount of smoke during combustion. However, complete combustion without visible smoke can be achieved when a sufficient air supply is provided (Piednoir Brice, 2017).

3.2.3 Ash content

The pellets produced exhibit an acceptable ash content in accordance with the French NF standard for solid biofuels, which specifies that the ash content of industrial-grade agricultural pellets must remain below 7%, while that of wood pellets should not exceed 3%. As reported by de Jesus et al. (2020), certain biomass resources, particularly agricultural residues, often display ash and nitrogen levels that surpass the upper limits prescribed by international standards. Mendoza Martinez et al. (2021) further indicate that ash content reflects the presence of inorganic constituents, mainly occurring in the form of oxides. Ash content is directly associated with the quantity of mineral matter and impurities retained within the fuel. The pellets produced in this study show higher ash contents than EN+ reference pellets, with the 33F33M33C formulation exhibiting the highest ash level (6.52%) and movingui wood pellets presenting the lowest ash content (5.22%).

3.2.4 Fixed carbon content

The fixed carbon content was highest for the 10F30M60C pellets (24.94%), followed by the 33F33M33C (20.59%) and 10F60M30C (20.47%) formulations. These results are consistent with those reported by Vitoussia et al. (2021), who produced pellets from blends of coffee pulp and palm kernel fibres using similar proportions. However, when compared with EN+ reference pellets, the fixed carbon levels obtained remain relatively low. This reduction may be attributed to the nature and chemical

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composition of the raw residues used. Fixed carbon content is a key indicator of fuel quality, as higher values are associated with increased calorific value and extended combustion duration. As reported by Ouattara et al. (2020), fuels with elevated fixed carbon contents generally burn more slowly and require longer residence times than those with lower FC values. This suggests that pellets produced from blended residues, particularly those containing coconut shells, may exhibit slower burning behaviour compared to pellets manufactured from single raw materials. Consequently, the relatively high fixed carbon content recorded for the 10F30M60C pellets (24.94%) may explain their elevated HCV.

3.3 Heat Calorific value of the produced pellets

The figure 3 below shows the Heat Calorific Value (HCV) of the residues and the HCV of the Pellets made from residues.

Across all samples, pelletisation led to an increase in HCV, confirming the efficiency of densification in enhancing the energy density of lignocellulosic biomass. The calorific improvement is explained by: (i) reduction in moisture content, which enhances combustion efficiency; (ii) improved compaction, resulting in higher energy per unit volume; and (iii) improved homogeneity, optimising fuel–air mixing during combustion. These results align with the findings of Kamga et al. (2024), who reported comparable post-pelletisation HCV increases of 5–10% for mixed agro-residues.

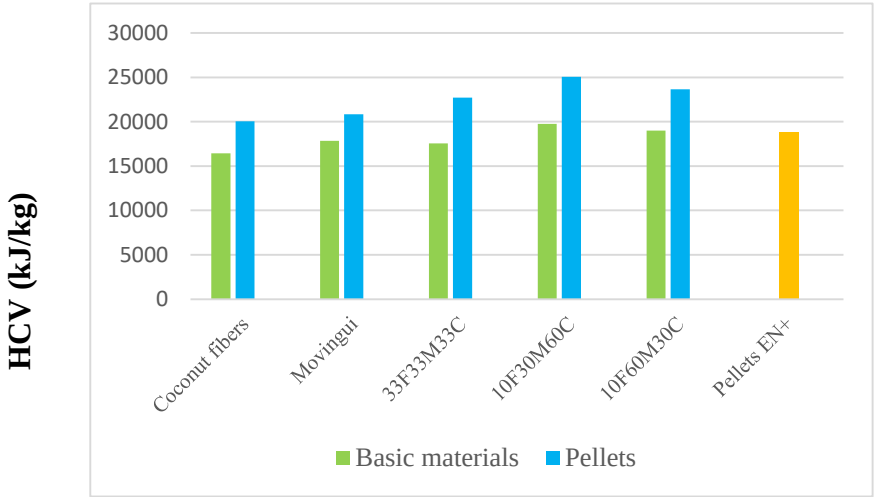

Figure 3: HCV of pellets and residues.

Palm nut shells exhibited an increase in HCV from approximately 18.89 MJ/kg in the raw state to about 19.77 MJ/kg when incorporated at 60% within the 10F30M60C formulation. This highlights the function of palm shells as a high-energy carrier and explains their predominance in the most efficient blends. Coconut fibres, despite their lower initial HCV (~16.43 MJ/kg), benefited from pelletisation through combination with higher-energy constituents. When included in the 10F30M60C and 10F60M30C blends, the overall calorific value increased by approximately 3–4 MJ/kg, demonstrating a synergistic calorific effect. Movingui sawdust showed a moderate improvement from around 17.84 MJ/kg in its raw form to nearly 19.01 MJ/kg within

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the 10F60M30C formulation, indicating that although it is not the main energy contributor, it enhances densification and promotes more uniform combustion. The 33F33M33C blend presented an intermediate gain (~17.54 MJ/kg), lower than that required for industrial-grade fuels, yet still suitable for rural thermal applications.

The 10F30M60C formulation clearly outperformed all other samples, both raw and pelletised, achieving an HCV close to 19.77 MJ/kg, approaching the upper range reported for non-torrefied biomass in the literature (20–21 MJ/kg) (Rashedi et al., 2022). This superior calorific performance can be attributed to: (i) the high proportion of palm nut shells (60%), which are rich in fixed carbon; (ii) the presence of a moderate fibrous fraction (10% coconut fibres) that enhances pellet cohesion without compromising energy density; (iii) the low post-pelletisation moisture content (~4.3%); and (iv) the inherent effect of pelletisation in consistently increasing HCV, confirming its effectiveness in converting residual biomass into dense, transportable solid fuels. Blending approaches therefore allow low-calorific residues to be upgraded into viable biofuels when combined with high-performance components. The 10F30M60C blend emerges as an optimal option for domestic cooking and small-scale heating applications in sub-Saharan Africa due to its elevated calorific value. Compared with firewood (18,288 kJ/kg) and charcoal derived from agricultural residues, pellets exhibit higher calorific values, although they remain well below that of liquefied petroleum gas (45,504 kJ/kg), which is a fossil fuel. Consequently, the pelletisation of alternative biomass resources as substitutes for commonly used wood fuels and fossil energy sources continues to be widely investigated in the literature (García et al., 2019).

3.4 Nature of residues under thermal condition

The purpose of thermogravimetric analysis is to predict the thermal behaviour of a given sample. This technique was used to determine the mass loss of the selected samples as a function of temperature or time. Mass variation with temperature and time is represented by the red TG curve. The black DTG curve identifies the onset and completion temperatures of degradation, as well as the peak degradation temperatures, while the blue DSC curve enables the quantification of heat flux released at each moment. It is well established that lignocellulosic biomass is mainly composed of hemicellulose, cellulose, and lignin. The thermal degradation process occurs in three distinct stages: the first two correspond to rapid devolatilisation phases, during which a substantial fraction of the sample mass is lost, giving rise to two pronounced mass loss peaks visible on the derivative thermogravimetric (DTG) curve; the third stage is characterised by slower degradation. Figure 4 below illustrates the TG–DTG–DSC profiles of palm nut shells.

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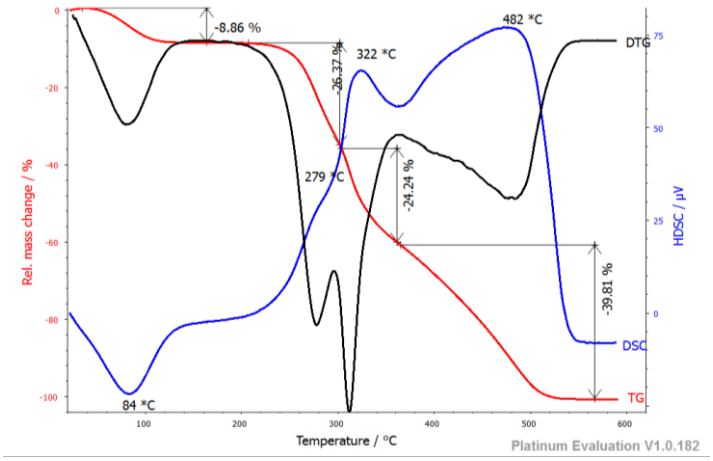

Figure 4 : Thermogravimetric analysis curve (TGA) of its derivative (DTG) coupled to the DSC of palm nut shells.

The TG analysis indicates that palm nut shells experienced a mass loss of 8.86% of their initial weight between 20 °C and 160 °C, which is associated with moisture evaporation. Likewise, within the temperature range of 200 °C to 300 °C, the first degradation stage of palm nut shells occurred, corresponding to hemicellulose decomposition and accounting for a mass loss of 26.37% of the original sample. Between 305 °C and 360 °C, the second degradation stage took place, attributed to cellulose breakdown, resulting in a mass loss of 24.24%. From 365 °C to 570 °C, the third degradation phase associated with lignin decomposition was observed, leading to a mass loss of 39.81% of the initial mass. The residual material, representing 0.72% of the original mass, corresponds to ash content. Figure 5 below presents the TG–DTG–DSC curves of coconut fibres.

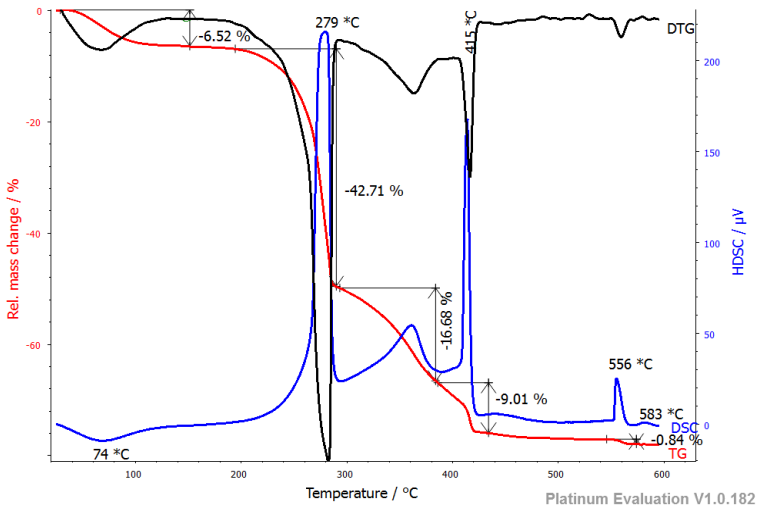

Figure 5 : Thermogravimetric analysis curve (TGA) of its derivative (DTG) coupled to the DSC of coconut fibers.

The TG–DTG thermograms indicate that coconut fibres underwent a mass loss of 6.52% of their initial weight between 20 °C and 150 °C, which is attributed to moisture removal. Likewise, within the temperature interval of 200 °C to 380 °C, the

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first degradation phase of these fibres occurred, corresponding to hemicellulose decomposition and accounting for a mass loss of 59.39% of the original sample. Between 380 °C and 435 °C, the second degradation stage was observed and is associated with cellulose breakdown, resulting in a mass loss of 9.01%. From 540 °C to 580 °C, the third degradation stage related to lignin decomposition took place, leading to a mass loss of 0.84% of the initial mass. Compared with other lignocellulosic components, lignin is generally the most resistant to thermal degradation. Although lignin decomposition may begin at temperatures as low as 160 °C, it proceeds gradually and can extend to temperatures approaching 900 °C, as reported by Klass D.L. (1998). Consequently, beyond 535 °C on the thermogram, the observed mass loss is attributed to lignin pyrolysis, with the 0.84% reduction indicating the completion of the pyrolytic process. The remaining fraction, representing 24.25% of the initial mass, corresponds to ash. Figure 6 below presents the TG–DTG–DSC curves of movingui sawdust.

The TG–DTG thermograms indicate that the thermal decomposition of movingui sawdust under ambient atmospheric conditions occurs through four successive stages. An initial dehydration phase up to 120 °C is observed, associated with a mass loss of 6.35%. This is followed by a first devolatilisation stage between 200 °C and 340 °C, during which a mass loss of 57.13% is recorded, with a peak at 328 °C. A second devolatilisation phase then takes place between 360 °C and 420 °C, corresponding to a mass loss of 24.94% and reaching a maximum at 412 °C. Finally, a minor mass loss is observed between 415 °C and 480 °C, amounting to 2.83%, with a peak at 447 °C.

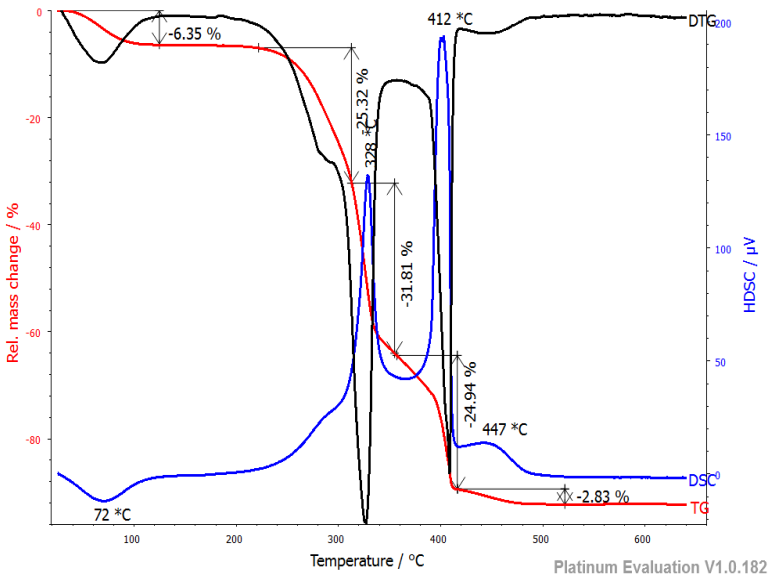

Figure 6 : Thermogravimetric analysis curve (TGA) of its derivative (DTG) coupled with DSC of movingui sawdust

Considering the decomposition temperature ranges of each biomass component, the thermal behaviour of the residues in ambient air demonstrates that palm nut shells undergo degradation at a much slower rate than the other two

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residues. Moreover, within the same temperature interval, palm nut shells require a longer combustion duration compared to coconut fibres and movingui sawdust.

3.5 Thermal behaviour of pellets from residue mixtures

The thermal behaviour of pellets produced from the base residue mixtures is illustrated in Figure 7. This figure below presents the TG–DTG–DSC curves corresponding to the 33F33M33C pellets.

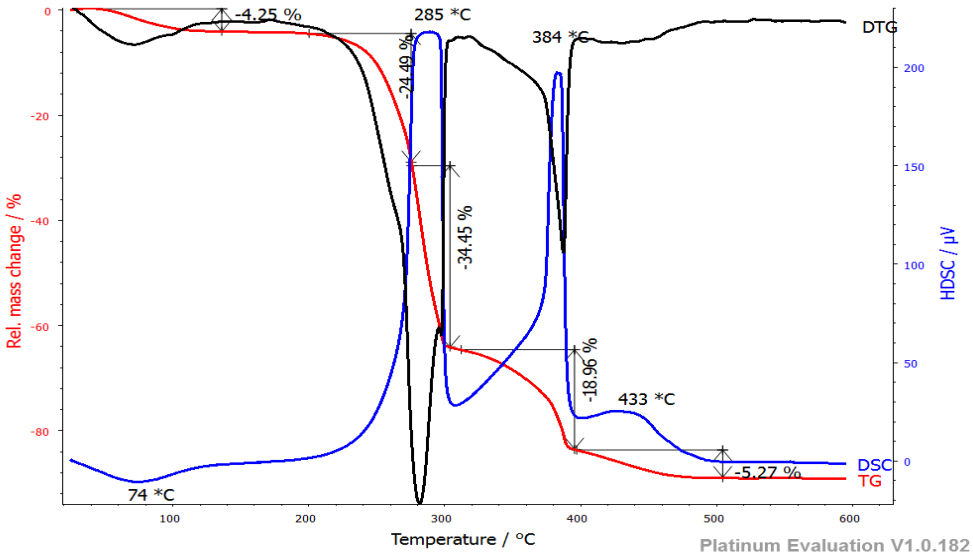

Figure 7 : Thermogravimetric analysis curve (TGA) of its derivative (DTG) coupled to the DSC of 33F33M33C pellets

Analysis of these curves indicates that the 33F33M33C pellets undergo thermal degradation marked by a mass loss of 4.25% of their initial weight between 20 °C and 140 °C, associated with an endothermic process linked to moisture evaporation. Likewise, within the temperature interval of 200 °C to 305 °C, these pellets experienced a mass reduction of 58.94%, corresponding to hemicellulose decomposition. Between 310 °C and 395 °C, an additional mass loss of 18.84% was observed, attributed to cellulose degradation. From 395 °C to 500 °C, the degradation process was related to lignin breakdown, resulting in a mass loss of 5.27% of the original sample. The residual fraction, accounting for 8.15% of the initial mass, represents ash content.

Figure 8 below presents the TG–DTG–DSC curves of the 10F30M60C pellets, composed of basic residues blended in proportions of 10% coconut fibres, 30% movingui sawdust, and 60% palm nut shells.

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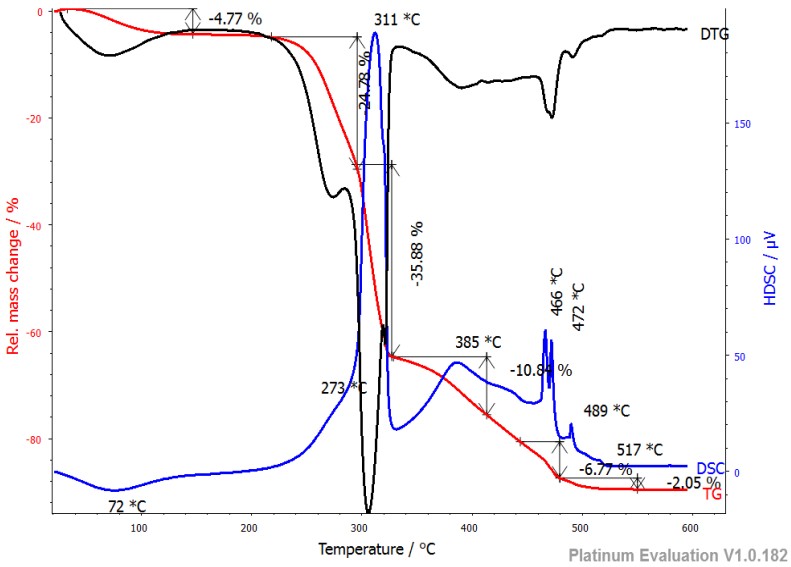

Figure 8: Thermogravimetric analysis curve (TGA) of its derivative (DTG) coupled to the DSC of 10F30M60C pellets

The TG analysis reveals that the 10F30M60C pellets underwent a mass reduction of 4.77% of their initial weight between 15 °C and 120 °C, corresponding to an endothermic process associated with moisture removal. Likewise, within the temperature range of 220 °C to 320 °C, these pellets exhibited a mass loss of 60.66%, with a maximum peak observed at 311 °C, corresponding to hemicellulose decomposition. Between 320 °C and 415 °C, an additional mass loss of 10.84% was recorded, attributed to cellulose degradation. In the temperature interval from 445 °C to 555 °C, with a peak detected at 517 °C, a further mass loss of 8.82% was observed, corresponding to lignin decomposition. The remaining fraction, representing 14.91% of the original mass, corresponds to ash content.

Figure 9 below illustrates the TG-DTG-DSC profiles of the 10F60M30C pellets, comprising basic residues blended at 10% coconut fibres, 60% movingui sawdust, and 30% palm nut shells by mass basis.

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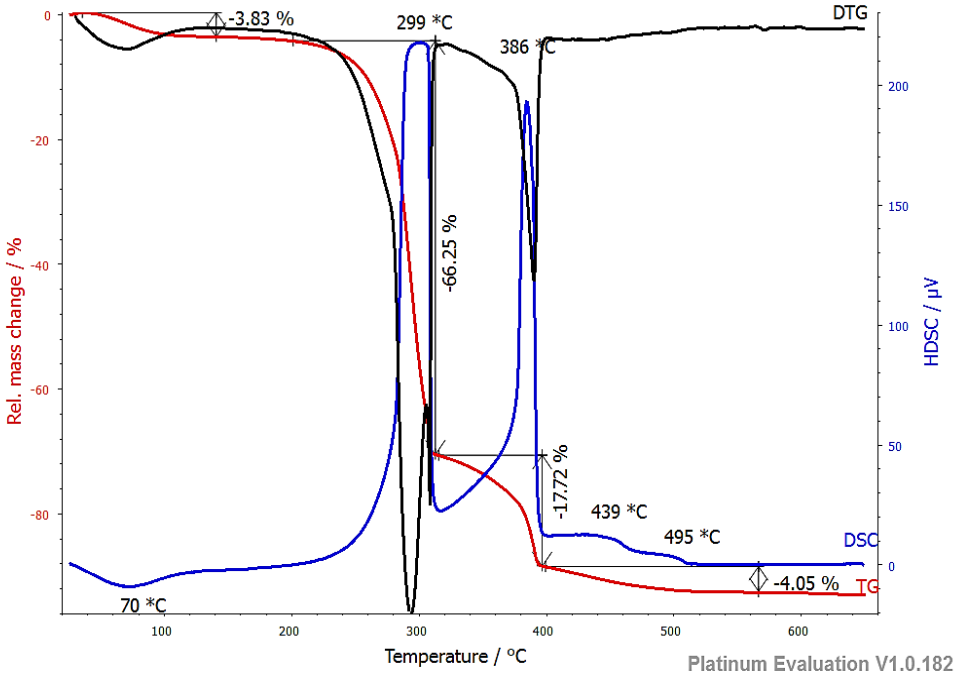

Figure 9 : Thermogravimetric analysis curve (TGA) of its derivative (DTG) coupled to the DSC of 10F60M30C pellets

The TG analysis indicates that the 10F60M30C pellets experienced a mass loss of 3.83% of their initial weight between 20 °C and 140 °C, corresponding to an endothermic process associated with moisture evaporation. Likewise, a substantial mass reduction of 66.25% was observed between 200 °C and 310 °C, reflecting the degradation of hemicellulose. Within the temperature range of 315 °C to 395 °C, a further mass loss of 17.72% occurred, corresponding to cellulose decomposition. From 395 °C to 565 °C, the degradation process was associated with lignin breakdown, resulting in a mass loss of 4.05% of the original sample. The residual fraction, accounting for 8.15% of the initial mass, represents the ash content.

For the 10F30M60C pellets, hemicellulose decomposition occurred over a broader temperature interval (220 °C–320 °C) compared with the other pellet formulations, suggesting enhanced thermal resistance when exposed to temperatures between 200 °C and 300 °C. The DTG profiles further indicate that 10F30M60C pellets exhibit superior thermal resistance, as cellulose degradation takes place at higher temperatures (320 °C–415 °C) relative to the other pellets. In contrast, lignin decomposition in the 10F60M30C pellets occurs across an extended temperature range (395 °C–565 °C), indicating improved thermal stability at temperatures exceeding 500 °C.

When subjected to heating between 200 °C and 565 °C, the 10F60M30C pellets therefore demonstrate increased stability. Compared with the other pellet formulations, they exhibit a longer degradation duration and a higher overall decomposition rate (88.02%).

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3 Conclusion

4.1 Main findings

This study investigated the energy performance of fuel pellets produced from agro-industrial and forestry residues, namely palm nut shells, coconut fibres, and movingui sawdust. Pelletisation effectively converted these residues into a dense, cylindrical solid biofuel with improved energetic and thermal properties, confirming the relevance of densification for biomass valorisation. Among the formulations tested, the 10F30M60C pellets exhibited the highest higher calorific value (25.07 MJ/kg), driven by their elevated fixed carbon content (24.94%) and low moisture level. Proximate analysis revealed that 10F60M30C pellets contained the highest volatile matter (69.61%), while 33F33M33C pellets showed the highest ash content (6.52%). Thermal analysis of raw residues indicated faster degradation of coconut fibres and movingui sawdust compared with palm nut shells, which displayed greater thermal stability. Thermogravimetric investigations demonstrated that blended pellets (10F30M60C, 33F33M33C, and 10F60M30C) degrade over a wide temperature range (200–565 °C) and exhibit higher thermal resistance than pellets produced from single residues. This improved behaviour is attributed to the presence of palm nut shells, which slow down thermal degradation and prolong combustion.

4.2 Implications and contributions

The results highlight the effectiveness of biomass blending strategies in enhancing pellet fuel quality. This study contributes to bioenergy research by providing a combined physico-chemical and thermal assessment of blended biomass pellets, demonstrating synergistic effects not achievable with individual residues.

4.3 Recommendations and future work

The 10F30M60C formulation is recommended for domestic heating and small-scale thermal applications in sub-Saharan Africa as a sustainable alternative to firewood and fossil fuels. Future studies should focus on emission characterisation, combustion performance in real stoves, mechanical durability, and techno-economic feasibility to support large-scale implementation.

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